PROGRESS REPORT

1. PI and Co-I Names and Affiliations

Peter H. Daum

Atmospheric Sciences Division

Building 815E

Brookhaven National Laboratory

Upton, NY 11973-5000

2. Title of Research Grant

   Studies of Cloud Microphysical and Optical Properties Using In-Situ Microphysical Data, Cloud Radar Data, and CART Measurements of Cloud Optical Properties

3. Scientific Goal(s) of Research Grant

   The goal of this project is to improve parameterizations of the microphysical properties of clouds for use in GCMs and in the remote sensing of clouds. We are currently focusing on the effect of the spectral dispersion of the cloud droplet size distribution on parameterization of the cloud droplet effective radius in liquid water status and stratocumulus clouds. The next step is to find a way to parameterize the spectral dispersion, which we expect to be closely associated with turbulent intensity. This seems feasible by combining in situ microphysical measurements with simultaneous measurements of turbulence with a cloud radar. This project relies heavily on cloud and aerosol data collected by aircraft during IOPs conducted at the CART/SGP site in Northern Oklahoma.

4. Accomplishments

   - Derived a generalized formulation for the response of optical particle counters that includes existing response functions as special cases.

- Developed an algorithm for correcting size distributions measured by optical probes for the difference between the refractive index of the calibration and ambient particles.
- Showed that light scattering coefficients calculated using uncorrected size distributions measured with an optical particle counter can differ from measured scattering coefficients by a factor of 2. After correcting the size distributions for particle refractive index measured and calculated scattering coefficients agreed to within 10%.
- Showed that the pre-factor α in a commonly used parameterization for the cloud droplet effective radius, i.e., $r_e = a(L/N)^{1/3}$, where L is the liquid water content and N the droplet number concentration, is dependent on the spectral dispersion of the cloud droplet size distribution.
- Showed that r_e s computed using parameterizations that assume fixed values of α, or α values computed assuming that cloud droplet size distributions can be represented by Gaussian, or lognormal distributions exhibit large errors when the spectral dispersion of the cloud droplet size distribution is large.
- Showed that the underestimation of r_e by widely used parameterization schemes is large enough to cause serious problems in climate modeling and the remote sensing of clouds.

5. Progress and accomplishments during the last twelve months

Our work over the past 12 months has focused on evaluation and development of parameterizations for the cloud droplet effective radius, r_e. Parameterization of this quantity as the cube root of the ratio of the cloud liquid water content (L) to the droplet concentration (N), i.e., $r_e = \alpha(L/N)^{1/3}$ is becoming widely accepted. However, a key issue in use of parameterizations of this type is specification of α. It can be easily shown that that α equals 62.04 for clouds that have a monodisperse size distribution. However, monodisperse size distributions are never observed real clouds; broader size distributions are observed even in clouds that are nearly adiabatic. Although it has been realized that α

depends on spectral broadening processes such as entrainment and mixing, research on this dependency has been very limited. During the past year we have undertaken an examination of the dependence of α on the spectral dispersion of the cloud droplet size distribution using cloud microphysical data that were collected during two recent IOPs at the ARM/SGP site in Northern Oklahoma.

Relationships derived by Pontikis and Hicks (1992) and by Liu and Hallet (1997) that purport to account for the dependence of α on the spectral dispersion of the cloud droplet size distribution were compared to each other, to parameterizations that assume constant values for α, and to the in situ cloud microphysical data. We found that the Liu and Hallet relation accurately represents the dependence of α on the cloud droplet spectral dispersion over a broad range of spectral dispersions. In contrast, the Ponkitis and Hicks scheme works well only when spectral dispersions are small, tending to underestimate the effective radius for clouds exhibiting broad size distributions. It was further demonstrated that the Ponkitis and Hicks parameterization, along with the parameterizations utilizing fixed pre-factors, exhibit biases in estimating the effective radius of a magnitude large enough to cause serious problems in climate models. The results of our work suggest that accurately representation of r_e in climate models may require predicting the prefactor (or the spectral dispersion of the droplet size distribution) in addition to the cloud liquid water content and droplet number concentration. The results of this study have been written up and have been accepted for publication in Geophysical Research Letters (GRL). A preprint of this manuscript is attached to this report. We are planning to extend this work by examining the role of turbulence in determining the spectral dispersion of the cloud droplet size distribution, hoping to find a tractable relationship between turbulence and α.

In an effort related to the above, we have also been examining the various ways that have been used to represent cloud droplet size distributions in models. Accurate representation of size distributions is important for calculation of a number of cloud properties including cloud microphysics and their evolution (for example by the so-called moment method), and for the remote sensing of clouds. Historically, cloud droplet size distributions have been represented by lognormal, Gaussian, or Gamma functions, less frequently by the Weibull function. In many calculations, unimodal size distributions are assumed. However there have been virtually no publications that have examined how well these various representations work, or what effect misrepresentation might have on derived cloud properties. We are in the process of addressing this issue by examining how spectral dispersions and cloud droplet equivalent radii derived assuming these various distributions compare to measured cloud properties. We argue that determination of the best mathematical expression for the droplet size distribution is equivalent to identification of the best parameterization of r_e, which in turn is equivalent to choosing the expression that best characterizes the dependence of α on the spectral dispersion of the cloud droplet size distribution. We have derived α as a function of the spectral dispersion of the cloud droplet size distribution for the Lognormal and Gamma distributions similar to the relationships that have been derived for the Wiebull and Gaussian distributions. We found that if droplet size distributions were represented by a Gaussian distribution, r_e was consistently too large, and for a lognormal distribution it was consistently too low. For both of these distributions, the error in determination of r_e was a strong function of the spectral dispersion of the cloud droplet size distribution. Equivalent radii computed assuming either a Gamma or Weibull distributions yielded values of r_e that were very close to the measured values of over the entire range of conditions that we examined. We conclude that cloud retrievals and cloud parameterizations need to be based upon either Gamma, or Weibull distributions to give accurate results. This result has significant implications for both the retrieval of cloud properties, and the representation of cloud properties in models as many of these algorithms assume lognormal distributions. The results of this study have been written up in draft form and will be submitted for publication in GRL shortly.

In a separate effort we have developed a new approach for modeling the effect of refractive index on the particle sizes measured by optical particle counters. Previously derived optical response functions were compared and a generalized formulation was derived, which includes existing response functions as special cases. Algorithms were derived for correcting size distributions measured by optical counters for the difference between the refractive index of ambient and calibration particles. Data collected by a

Passive Cavity Aerosol Spectrometer (PCASP) and by an integrating nephelometer during two of the recent aerosol IOPs at the SGP CART site were compared. Light scattering coefficients calculated from the optical probe data uncorrected for refractive index differed from those measured by the integrating nephelometer by a factor of 2. An iterative procedure that adjusts the PCASP-measured size distribution for the effect of refractive index was used to derive the best agreement between calculated and observed light scattering coefficients. The aerosol refractive indices that best fit the data varied between 1.3 and 1.5 with an average of 1.41. The relative importance of the underestimation of light scattering coefficients calculated from the PCASP-measured size distributions due to the refractive index and the size truncation effect were also evaluated. The former was found to be more important than the latter. Implications of this study for addressing aerosol shortwave radiative forcing and potential uncertainties relevant to this study are discussed. This work has been recently published in *J. Aerosol Science*. *J. Aerosol Sci*. **31**, 945-957 (2000).

6. As appropriate, attach one or so electronic figures with paragraph discussions highlighting current research. Label with PI name, affiliation, and year. We will use these in presentation materials.

   NONE

7. List all *refereed* publications either submitted or published during the *current* grant FY that acknowledge DOE ARM support.

   Publications-

   Liu, Yangang and Daum, P. H. The Effect of Refractive Index on Size Distributions and Light Scattering Coefficients derived from Optical Particle Counters. *J. Aerosol Sci*. **31**, 945-957 (2000).

   Liu, Yangang and Daum, P. H. Spectral Dispersion of Cloud Droplet Size Distributions and the Parameterization of Cloud Droplet Effective Radius. *Geophys. Res. Ltrs*. (In press) (2000).

8. List all published (either paper or web-based) extended abstracts in the current FY that acknowledge DOE ARM support. Two copies of each should accompany the progress report*.

   NONE

9. Please update us on the status of submitted referred publications from the previous FY progress report.

   NONE

*Via ordinary mail

References

Liu, Y and J, Hallett, The 1/3 power-law between effective radius and liquid water content, *Q. J. R., Meteor Soc.*, **123**, 1789-1795, 1997.

Pontikis, C., and E. M. Hicks, Contribution to the droplet effective radius parameterization, *Geophys. Res. Lett*., **19**, 2227-2230, 1992.